Naval Submarine Medical Research Laboratory

NSMRL Report No. 1237 18 August 2004

EXERCISE ABOARD ATTACK SUBMARINES: RATIONALE AND NEW OPTIONS

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ABSTRACT

Substantial scientific evidence supports the potential benefits of exercise for submariners: regular exercise improves many human functions that directly apply to submarine operations. These benefits include improved alertness, cognitive function, immune function, weight control, strength and fitness (for damage control, etc.), mood state, responses to stress, sleep quality, and quality of life. However, most submariners do not exercise during deployment for a variety of reasons, including lack of space, time limitations, equipment limitations, lack of entertainment or recreational value associated with exercise, low oxygen levels, high carbon dioxide levels, and hygiene challenges. A need exists to significantly improve participation in and effectiveness of exercise for submariners, in part by increasing the variety and effectiveness of available exercise options, and also by making exercise on submarines more enjoyable. Submarine Fitness Coordinators report that equipment limitations constitute one of the most important and addressable problems. Fitness Coordinators and the authors identified the following desirable exercise device characteristics: effective, durable, safe, quiet, small, fun, easy and convenient to use, and not unduly expensive. Several existing and emerging exercise technologies exist to improve upon those currently in use aboard submarines. Integration of virtual environments with exercise hardware represents one of the most interesting and promising emerging technologies. Improving exercise capabilities for submariners also augments the means and ability for special operations units deployed aboard submarines to maintain fitness.

ADMINISTRATIVE INFORMATION

The views expressed in this report are those of the author(s) and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government.

This report; was approved for publication on 18 August 2004, and designated as Naval Submarine Medical Research Laboratory Report #1237.

Why Maintain fitness aboard submarines?

Substantial scientific evidence supports the potential benefits of exercise for submariners: *exercise improves many human functions that directly apply to submarine operations*. Cognitive performance (response time, focused searching tasks) is improved following exercise (1, 28). Anecdotally, watchstanders report that exercise before standing watch delays and reduces the need to drink coffee. Moderate exercise may help protect against upper respiratory tract infections (13, 17), which often spread pervasively in the closed environment of submarines.

Like many modern workplaces, submarine life and work are largely sedentary. The inactivity of submarine life worsens effects of reduced exercise and emphasizes the need for exercise on submarines: for example, Bondi and Dougherty (3) found that crewmember activity during deployment decreased to about half of that seen before deployment, as measured by pedometry. Not surprisingly, submariners (2) and Sea Air Land Special Operations Forces (SEAL) passengers on boats (9) experience loss of physical fitness while underway. Bennett and co-workers (2) noted a 7% reduction of maximal oxygen consumption in non-exercising submariners following a 70-day submarine deployment. Similarly, Fothergill and Sims (12) saw a 7% decrease in distance run in 12 minutes in SEAL personnel following a 33 day deployment.

The stress and duration of submarine patrols can lead to mood disturbances such as anxiety and depression (20). Regular exercise improves measures of intelligence and mood state, and reduces anxiety responses to stress (8, 10, 18, 28). Medical reasons (including psychiatric and weight control problems) accounted for 373 of the 709 disqualifications (53%) from the US submarine service in 1996 (data from Bureau of Personnel Code 41). In general, workplace fitness programs decrease employee sickness (14, 16). Therefore, it is conceivable that regular exercise on submarines could reduce attrition from medical causes.

Given the current 18-h watchstanding schedule aboard US submarines (6 h watch, 12 h off), any strategy to increase sleep quantity and quality will improve operational performance. Exercise can decrease the time it takes to go to sleep and also improve sleep quality (7, 23). Furthermore, a recent study found that exercise decreased some of the sleep disturbances caused by high caffeine intake (29). Taken together, the above listed benefits clearly suggest that regular exercise could improve submariners' work performance *and* quality of life during deployment. Improved quality of life at sea could also help reduce attrition from submarine service. Therefore, many excellent reasons exist for submariners to exercise regularly. The Table below summarizes these reasons and their operational relevance. Not surprisingly, the Chief of Naval Operations Instruction for exercise (6110.1G) corresponds well with the American College of Sports Medicine Position Stand concerning maintenance exercise for healthy adults (19).

Why do most submariners not exercise during deployment?

A standardized survey of 10 US fast attack submarine Fitness Coordinators indicated that 35 ± 12% of their shipmates exercised regularly while underway (mean ± SD). Several reasons exist for why submariners tend to not exercise, including:

Table: Rationale for improving exercise options for submariners

Submariner Problem/Challenge	***Exercise Benefit***	***Operational Relevance***
inactivity -> reduced strength and fitness	maintain strength and fitness	damage control, sustained operations, submarine escape
inactivity -> weight gain	increased metabolism, weight control	improved general health, better fit into small living spaces
closed environment -> immune system challenges	reduced respiratory infections	decreased sickness-induced performance degradation
submarine life -> mood disturbances	improved mood state, reduced anxiety from stress	improved individual and interactive performance
alertness through 6-h watch	increased alertness	improved watchstanding function, decreased reliance on stimulants
18-h schedule -> reduced sleep quality, quantity	improved sleep quality, efficiency	increased alertness and cognitive function
attrition for medical reasons or chronic PRT failure	improved health and quality of life	increased retention

1. The most obvious reason is that submarines contain very little living space, and most of what space there is serves purposes other than exercise or is not conducive to use for exercise. Attack submarines are not normally equipped with much exercise equipment due to these space constraints. Furthermore, exercise equipment most commonly resides in the engine room due to the space available.

2. Time limitations: the 18 hour watchstanding routine and schedule variations due to All Hands events (drills, Field Day, Battle stations training, actual casualties, emergent repairs, etc.) make it difficult to establish an exercise routine. Like many of us, submariners rightfully choose sleep over exercise when such a choice must be made.

3. Submarines commonly lack resistance training capabilities. Free weights are discouraged due to noise, stowage, and safety concerns.

4. Exercise capabilities currently on subs do not offer much entertainment or recreational value. This problem is particularly important in the confined and stressful environment of submarine life, but it is not unique to submarines. In fact, many people in the general population avoid exercise in part because it is a "chore" instead of a fun activity.

5. The exercise equipment submarines carry is usually not designed for the demands and limitations imposed by use aboard submarines. It may not fit well into confined spaces, it may require time to set up, or it may break down or require excessive maintenance.

6. Low oxygen and high carbon dioxide levels on US submarines probably make exercise somewhat more fatiguing than similar exercise at 21% oxygen (12). US submarines maintain atmospheric oxygen at 18-19% (at normal atmospheric pressure) for purposes of fire suppression. This percentage approximates the oxygen available at 1000 m (3280 ft) altitude, which may produce a small decline in aerobic work capacity, and slightly increased perceived exertion and fatigability relative to sea level oxygen partial pressure conditions (27). High carbon dioxide (on submarines, 0.5-4.0%; (22)) also impairs exercise responses (11). Furthermore, low oxygen combined with high carbon dioxide is more physiologically stressful than either condition by itself (24).

Other reasons also discourage exercise on submarines. As noted above, equipment commonly resides in the engine room, which is usually warm enough to reduce thermal comfort during exercise. Exercise increases oxygen consumption and supply requirements, carbon dioxide production and scrubbing requirements, inhalation of and thus exposure to submarine atmosphere constituents, potable water consumption and supply requirements, food consumption and supply requirements, noise, and use of laundry supplies and equipment. However, submarine life-support systems are more than capable of supporting the additional demands of regular crew exercise. Also, the collective scientific evidence presented above makes a very strong case that benefits of exercise on submarines outweigh any disadvantages. Obviously, the purpose of submarines is not to provide exercise for their crews. On the other hand, as discussed above, crew fitness facilitates optimal and effective submarine operation, especially in demanding conditions such as sustained operations, damage control, and submarine escape.

A need exists to significantly improve participation in and effectiveness of exercise for submariners, in part by increasing the variety and effectiveness of available exercise options, and also by making exercise on submarines more enjoyable. Attention focuses primarily on attack submarines because they contain much less discretionary volume for exercise equipment than the relatively larger Trident submarines and surface ships. Successful exercise equipment on attack submarines may well be implemented on other platforms.

Some alternative exercise options to consider

Submarine Fitness Coordinators report that equipment limitations constitute one of the most important and addressable problems, and correction of equipment limitations may help alleviate some of the non-equipment limitations. For example, crewmembers may feel more encouraged to exercise if it uses their time efficiently, is enjoyable, and/or more directly addresses their fitness desires (for example, aerobic *and* strength training).

Currently popular exercise devices such as upright cycle ergometers, steppers, and the Versaclimber should continue to be supported. Importantly, a treadmill (Quinton Clubtrack 510) has been approved for use aboard attack submarines, so no need exists to revisit this conclusion. However, as Vickers and co-workers noted in 1982 (25), "providing exercise facilities does not ensure their use" on submarines.

Attack submarine Fitness Coordinators and the investigator team identified these desirable exercise device characteristics:

- Effective, time-efficient maintenance of fitness
- Durable enough to withstand high use with very low or no maintenance
- Safe/non-injurious, including during ship movement
- Quiet, so as not to disturb submarine operations or sleeping crew
- Small enough to fit through hatches and passageways, to fit in areas for exercise gear, and to avoid impeding access/operations
- Fun, to allow crew recreation, enhance quality of life, and encourage use
- Easy and convenient to use; minimal time spent with device set-up ("walk up, work out, walk away")
- Cost-effective: expense of the device is reasonable and not prohibitive.

Some exercise options to consider include the following, and other unexplored options probably also exist.

Weight vest worn during running in place, calisthenics, and stepping

This is a heavy duty nylon vest constructed with numerous pockets on the front and back into which the exerciser places small weights. The user may add between 1 and 40 kg (~2-90 lb) of weight to the vest. Adjustable straps secure the vest around the exerciser's chest. The user may run in place, perform stepping exercise (on a small locker, for example), and perform multiple calisthenics while wearing the weight vest (for example, see one possible program at weightvest.com/chart.html). In addition to use by submariners, training with a weight vest could be particularly valuable for SEALS on submarines in transit to a mission, in part as a means of simulating the loaded backpack they might carry during an operation. Commercially available units cost ~$100-200.

Respiratory muscle training (RMT)

Respiratory muscle training (RMT) is a relatively recent training technique that improves submaximal cycling exercise endurance up to 50% (4-6). RMT involves breathing at a high

ventilation volume (hyperventilation) against minimal resistance with the remainder of the body at rest. Hypocapnia is avoided by partial rebreathing from a bag. The RMT system controls the degree of rebreathing and therefore also avoids hypercapnia. The improvement in endurance capacity with RMT is associated with lower blood lactate levels during exercise as well as a 300% increase in breathing endurance (i. e. ability to maintain 75% of maximal voluntary ventilation). Researchers at the Center for Research and Education in Special Environments at the State University of New York at Buffalo are currently evaluating RMT for use by divers and Special Forces personnel. Preliminary results suggest that RMT improves submaximal exercise endurance at depth (26) and altitude (15) as well as running endurance at normal ambient pressures (Lundgren, personal communication).

The advantage of RMT over traditional aerobic training methods is that RMT can be performed in a limited space with minimal equipment by multiple individuals at the same time. Our intent of RMT for submarine use is not to recommend it as a general and full substitute for traditional aerobic training, but to suggest its utility for maintaining aerobic endurance when traditional methods of aerobic training are not available or practical during deployment. This may be the case aboard fast attack submarines during operations where Special Forces personnel and equipment utilize the space normally assigned for traditional exercise equipment. RMT may also serve as an adjunct to traditional training methods. One commercially available RMT unit costs ~$700 (spirotiger.com), but it could be made for much less.

Exercise in virtual environments

Obviously, virtual environment technology is not an exercise technology per se, but its use may improve submariner participation in exercise by making exercise fun. For submariners and others, motivation to exercise suffers when exercise offers no entertainment or recreation. If exercise is made fun or associated with fun activities, then motivation to exercise is “built in”. One example of commercially available exercise virtual environment technology appears at fitcentric.com (software $100; virtual courses $10-25; hardware (hundreds?)). Virtual environment hardware and software may be integrated with a variety of different aerobic exercise devices (treadmills, cycles, etc.).

Exercise on submarines does not currently offer much if any entertainment or recreational value. Also, submarines lack many other common sources of entertainment and recreation, which adds to the stress of submarine life. Submariners commonly listen to music on personal stereos during exercise, but exercise in a virtual environment or watching a video during exercise would probably be significantly more enjoyable. Fitness clubs commonly place TVs in front of exercise equipment.

In submarines, openly visible virtual environment displays or video could distract other crewmembers working nearby, hence the suggestion for personal, head-mounted display for accompanying exercise on submarines. Another concern is attentiveness to alarms: as with personal stereos, submariners using head-mounted displays during exercise would need to keep the sound volume low enough to hear alarms.

Keiser comprehensive resistance exerciser (SubX-1)

Fitness Coordinators commonly cited lack of strength training equipment as one of the most significant exercise device deficiencies on fast attack submarines. Importantly, submariners require maintenance of strength to cope with emergencies such as damage control and submarine escape, and the many other benefits of exercise for submariners are discussed above. For a variety of reasons (size, set-up time, poor performance, lack of durability), strength training equipment tried on attack submarines to date (Soloflex, Bowflex, Nordicflex) has not been widely adopted.

A resistance exercise device should allow full range of motion, and continuous resistance adjustment and range from low force levels such as those needed by a relatively small user for circuit training (high repetitions) to the high force levels that a relatively strong user would employ at <10 repetitions to maintain or increase strength. Ideally, the device should provide resistance up to that needed for one maximum repetition. For circuit training, the speed a user can change from each exercise to another is important, because "down-time" between exercises diminishes the aerobic benefit of circuit training.

Based on a concept by Schwandt et al. (21), Keiser, Inc. designed and built a comprehensive resistance exercise device to help counteract muscle deconditioning during long term space flights (the SX-1). A NASA Small Business Innovative Research grant supported this project. A prototype of the Keiser comprehensive resistance exerciser for submarine use can be constructed (the SubX-1, below right). Keiser equipment employs pressurized air cylinders to create resistance for exercise. The cylinders reach internal pressures of 120-180 PSI.

The SubX-1 would provide the following resistance exercises: leg press, bench press, row, shoulder press, and lat pull. In addition, the upper body exercise component would rotate continuously between shoulder press position and bench press position to exercise the arms and pectoral girdle at any point and in either direction within this range of motion. Resistance for all exercises is continuously variable during exercise using thumb buttons at the ends of the machine's handgrips, which control air pressure in the cylinders. (SubX-1 prototype: $25,000; production unit: ~$12,000)

Other companies may also be interested in developing exercise hardware for use aboard attack submarines, particularly if they see that such hardware could supply markets larger than the Navy.

ACKNOWLEDGEMENTS

We thank the 12 attack submarine fitness coordinators interviewed for this work for their valuable insights and recommendations, and we thank Maria Fitzgerald for her professional technical assistance.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
08-18-2004	Final	2004

4. TITLE AND SUBTITLE

EXERCISE ABOARD ATTACK SUBMARINES: RATIONALE AND NEW OPTIONS

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

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5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NAVSUBMEDRSCHLAB
Box 900
Groton, CT 06349-5900

8. PERFORMING ORGANIZATION REPORT NUMBER

NSMRL Technical Report #TR1237

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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15. SUBJECT TERMS

Submarines, fitness, exercise devices, submariner health, exercise technology

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			M. Fitzgerald, Publications Manager
U	U	U		15	19b. TELEPHONE NUMBER *(Include area code)* (860) 694-2442

14. Abstract (cont)

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